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APRIL 1966 REPORT 1 ROCKET-BLAST-RESISTANT MATERIALS

MISCELLANEOUS PAPER NO. 4-804

ROCKET - BLAST - RESISTANT MATERIALS

Report 1

ROCKET ENGINE BLAST TESTS ON EXPEDIENT SURFACING MATERIALS

by

G. W. Leese

April 1966

Sponsored by

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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U. S. Army Materiel Command
Project No. 1-V-0-21701-A-046
Task 05

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ARMY-MRC VICKSBURG, MISS.

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FOREWORD

The general authorization for this investigation was contained in Research and Development Project Card for Mobility Engineering Support, Project No. 1-V-0-21701-A-046, Task No. 05, approved June 1960. This investigation was performed under the sponsorship of the Research and Development Directorate, U. S. Army Materiel Command.

The tests reported herein were conducted in the Surface Effects Blast Facility of the U. S. Army Engineer Waterways Experiment Station (WES) during March to August 1962 by personnel of the WES Soils Division under the general supervision of Messrs. W. J. Turnbull, W. G. Shockley, A. A. Maxwell, and W. L. McInnis and the direct supervision of Mr. G. W. Leese. This report was prepared by Mr. Leese.

Directors of the WES during the conduct of this investigation and preparation of this report were Col. Alex G. Sutton, Jr., CE, and Col. John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

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SUMMARY

Experience has shown that the exhaust blasts of missile and rocket firings will cause considerable soil erosion and large dust clouds over unprotected ground surfaces in the launching areas. Since missiles and rockets are used tactically as artillery and antiaircraft weapons in support of forward ground operations, control of blasts to prevent soil erosion and dust clouds is necessary for personnel and equipment protection, launcher stability, and camouflage and concealment.

Blast tests with a 500-lb-thrust rocket engine were conducted on (a) ceramic-coated aluminum blast panels, (b) steel panels, (c) plastic panels, and (d) nylon membrane with and without a heat-resistant coating to determine the capabilities of these items to withstand the high temperatures and velocities generated during the firings.

Based on results obtained in this investigation, the following conclusions are believed warranted:

- a. The ceramic coating on the aluminum panels and the heat-resistant coating on the nylon membrane greatly increase the capabilities of these items to resist the rocket engine exhaust blasts.
- b. The steel panels without protective coating will withstand exposure to higher blast temperatures than will the ceramic-coated aluminum panels.
- c. The plastic panels sustained considerable damage during exposure for 20 sec to the full-stage blast of the model engine.

ROCKET-BLAST-RESISTANT MATERIALS

ROCKET ENGINE BLAST TESTS ON EXPEDIENT SURFACING MATERIALS

PART I: INTRODUCTION

The Problem

1. Observation of firings of rockets and missiles from unprotected launching areas revealed that considerable soil erosion and dust clouds were caused by the engine exhaust gases impinging on the exposed ground surface. Since missiles and rockets are used tactically as artillery and antiaircraft weapons in support of forward ground operations, blast control to prevent undesirable soil erosion and dust cloud formation is considered desirable for personnel and equipment protection, launcher stability, and camouflage and concealment. Thus, blast-resistant materials suitable for use in the exhaust blast impingement area are necessary to prevent undesirable blast effects.

Purpose and Scope of Investigation

2. The purpose of this investigation was to determine the ability of various expedient surfacing materials to withstand the direct blast of a rocket engine. The objective was accomplished by a series of model rocket engine firings over the surfacing materials in the Surface Effects Blast Facility of the U. S. Army Engineer Waterways Experiment Station (WES).

PART II: MODEL ENGINE AND TEST ITEMS

Model Engine

3. The model rocket engine used to produce blast velocities, pressures, and temperatures was developed by the Lewis Research Center, Cleveland, Ohio, for use in model-scale space booster wind-tunnel studies. The engine has a nominal thrust of 500 lb, an exhaust velocity (characteristic) of about 5400 fps, exhaust gas temperatures capable of exceeding 4000 F, and an expansion ratio (throat area to nozzle exit area) of 1:12 and uses JP-4 and liquid oxygen as fuel and oxidizer, respectively. It is cooled by water circulating under high pressure between the inner beryllium-copper combustion chamber and the outer brazed-wire-wrapped water jacket. The engine is ignited by first igniting gaseous oxygen and propane gas utilizing a spark gap; the JP-4 liquid-oxygen mixture is then ignited by the burning oxygen-propane gas mixture.

Test Items

4. The expedient surfacing materials investigated during this study included (a) ceramic-coated aluminum blast panels, (b) steel panels, (c) plastic panels, and (d) nylon membrane with and without a heat-resistant coating (Dyna-Therm).

Ceramic-coated aluminum panels

5. A ceramic coating was placed on the surface of T11 aluminum landing mat panels extruded from 6061-T6 aluminum alloy to increase the heat and abrasion resistance of the panels. Each panel was 2 ft 1-7/8 in. wide and 12 ft long and weighed about 120 lb (photograph 1). The panels were interlocked along the sides with a hinge-type connector and connector slot. Panel ends were connected by hollow aluminum bars riveted to the panels. Details of the panel design are shown in Corps of Engineers drawing No. E-10003-1, which is on file at WES. A porcelain enamel was applied on the surface of the panels and overlaid with a carbide facing to form a coating 0.007 in. thick. Preliminary tests had indicated that a coating greater than 0.007 in. thick probably would crack and spall when the panel was flexed.

Steel panels

6 The steel panels were experimental T10 landing mat panels formed of FS1015-1020 material by rolling and press-braking operations. Each panel was 1 ft 7-1/2 in. wide and 11 ft 9-3/4 in. long and weighed 146-3/4 lb (photograph 2). Details of the design are shown in Corps of Engineers drawing No. M7613-1, which is on file at WES. The surface of the panel is broken by four ribs paralleling the long axis. The side connection is made

by inserting connector hooks into connector slots; the ends are fastened together by sliding steel pins along the bottoms of the ribs. The panels were coated with olive-drab paint to prevent rusting.

Plastic panels

7. T13 plastic landing mat panels were used in these tests. The panels were sandwich structures fabricated of phenolic-resin-impregnated, glass-fabric honeycomb core bonded top and bottom to laminated epoxy-resin-impregnated, glass-fabric facings (photograph 3). Each panel was approximately 3 ft wide, 12 ft long, and 1-3/4 in. thick and weighed approximately 194 lb. Panel connections were made with extruded aluminum connectors which were bonded to the panel sides and ends; the connectors were secured by aluminum connector locking beams. The panel is shown in detail in Corps of Engineers drawing No. F-10005-1, which is on file at WES.

Membrane and blast coating

8. Membrane. The membrane (T12) used in these tests was a neoprene-coated nylon that was developed for waterproofing and dustproofing roads, airfields, and helicopter landing pads. The woven nylon base fabric weighed 8 oz per sq yd and, as procured for use on roads and airfields, was coated on each side with 16 oz of neoprene per square yard. The finished weight of the membrane was 2-1/2 lb per sq yd, and its tensile strength was about 400 lb per lin in. The material was supplied in 100-yd-long by 36-in.-wide rolls. The membrane can be joined by sewing or bonding with adhesives to form large sections. Membrane specimens used in these tests were 24 in. wide by 28 in. long.

9. Blast coating. The coating applied to the T12 membrane was an intumescent protective material containing phosphate and boron flame-retardant compounds dispersed in a flexible polyurethane binder that could be troweled, brushed, or sprayed on a surface to the desired thickness. The coating, known as Dyna-Therm, was sprayed on a test specimen of membrane to a thickness of about 0.125 in.

Ceramic-Coated Aluminum Panels

10. The ceramic-coated aluminum panels were fastened lengthwise and positioned with the long axis at right angles to the rocket engine exhaust nozzle so that the blast would impinge on the panel at a 45-deg angle; the distance from the exhaust nozzle to the center of blast impingement was approximately 77-3/4 in. Four platinum-type thermocouples were installed in the panels to measure the blast temperatures at the panel surface. Photograph 4 shows the test area before the test and the location of the thermocouples which were installed so as not to cause any discontinuity or breaks in the panel surface. These thermocouples were connected to wide-band differential amplifiers, and continuous recordings were made during the tests. Movie cameras recorded the test.

11. The test in progress after about 11 sec is shown in photograph 5. The upward bowing of the panels indicates a large heat differential between the top and bottom surfaces of the panel. It will be noted in photograph 5 that the surface coating was just beginning to fail. Photograph 6 shows the impingement area after the test. Thermocouples in the burned area indicated that the panels withstood the blast for about 15 sec before complete burn-through occurred. A study of the movie film indicated that surface burn started about 10.5 sec after the test was begun.

12. The total time of exposure of the ceramic-coated panels to the exhaust blast of the rocket engine was 21.2 sec, during which time the maximum recorded temperature on the panel surface was 2500 F (see plate 1).

Steel Panels

13. Three firings of the rocket engine were made on the steel panels. The first and second tests were conducted to determine the effect of gas flow along the long axis of the panels and to obtain temperature data; the third test was conducted to determine the effect of gas flow across the long axis of the panel.

First test

14. Interlocked panels were placed beneath the rocket engine so that the exhaust blast path would be parallel to the long axis of the panel and blast impingement would be in approximately the center of a panel. The panels were subjected to exhaust blast for 32 sec. The angle of impingement on the panel surface was 45 deg, and the distance from the engine exhaust nozzle to the center of the impingement area was 86 in. Platinum-type thermocouples spaced 5 in. apart were inserted in the panels to record exposure temperatures. The thermocouples were connected to wide-band

differential amplifiers, and continuous recordings were made during the test. The test area and the location of the thermocouples as viewed from the rocket engine exhaust nozzle are shown in photograph 7.

15. Photograph 8 shows the blast test in progress, and photograph 9 shows the condition of the panels after test. Only the side connector that presented a surface discontinuity to the flow of the hot, high-velocity gases was damaged. The maximum temperature recorded during the test was 3200 F, but the center of impingement was slightly to one side of thermocouples 1 and 2 (see photograph 7). Photograph 10 is a close-up of the damaged area.

Second test

16. The setup for the second test was identical with that for the first test, except the panels were moved slightly to one side so that the first thermocouple would be in the center of blast impingement and a panel damaged during the first test was replaced. Time of exposure to the hot exhaust gases was 30 sec.

17. Photograph 11 shows the steel panel surface after the second test; again damage occurred along the side connector that was raised against the flow. Maximum temperature recorded in the blast impingement area was 3300 F. Color movies taken during the test showed the impingement area as a glowing red spot when the engine was cut off.

18. During the test, temperatures on the surface of the panels were recorded from thermocouples 1, 2, 4, and 6. Thermocouples 3 and 5 were damaged by the blast force and did not function properly. Thermocouple locations can be seen in photograph 7. The following maximum temperatures were recorded.

Thermocouple No.	Maximum Temperature, °F
1 and 2	3300
4	2540
6	1960

It should be noted that these are temperatures of the exhaust gas on the surface of the panels and not temperatures of the panels.

Third test

19. The third test differed from the first two tests in that the panels were turned so that the long axis was transverse to the blast. With the panels in this position, the rocket engine exhaust gases flowed across the panel ribs rather than along them. Time of exposure to the hot exhaust blast was 30 sec. Thermocouples were not inserted in the panels for this test, since considerable temperature data had been obtained in the two previous tests and no changes were made in engine operation or position for the third test.

20. Photograph 12 shows the blast impingement area of the steel panels after the third test as viewed from the rocket engine exhaust nozzle. Considerable damage was done to the panel as the hot exhaust gases impinged against the rib sections. The abrupt change in surface at the edge of each rib of the panel apparently caused concentration of heat which in turn burned the steel at these points. A comparison of photographs 9 and 12 shows that the blast along the panel ribs caused less panel damage than that across the ribs.

Plastic Panels

21. Three side-interlocked plastic panels were placed beneath the rocket motor so that the motor blast would exhaust parallel to the long axis of the panels and at a 45-deg impingement angle. The distance from the nozzle of the rocket engine to the center of impingement was 77-3/4 in. The panels were exposed to full-stage rocket blast for 20 sec. Thermocouples were not used in this test, but based on temperatures in previous blast tests with similar test conditions, it was estimated that maximum temperatures would be between 2500 and 2800 F. Photograph 13 shows the main impingement area on the middle panel as viewed from the engine nozzle just before the test. The connector locking beams were flush with the panel surface, but the wider aluminum strip along the left panel (photograph 13) was slightly above the panel surface.

22. Photograph 14 shows the test in progress and the panels burning. After the engine was cut off, the plastic panels continued to burn until the flames were extinguished with water. Photograph 15 shows the panels after the test. Separation of the laminated layers of glass cloth in the top facings can be noted on all panels. The top facing was completely removed from about half of the middle panel, leaving the honeycomb core exposed. Photograph 16 shows the main impingement area as viewed from the engine exhaust nozzle after the test, and photograph 17 shows globules of molten glass in the exposed honeycomb core. Comparison of photographs 13 and 16 shows that the aluminum connector locking beams which were in the same plane as the panel surface were not damaged, whereas the aluminum strip which was slightly higher than the panel surface was burned away. Study of high-speed movies of the plastic panel test indicated that damage to the panel surfaces started about 3 to 4 sec after full-stage blast, and complete destruction of the top facing of the middle panel occurred after 15 sec of exposure; the bottom facing was not damaged during the test.

Membrane and Blast Coating

Uncoated membrane

23. The membrane was tested initially without protective coating to determine the capability of the material to resist heat. Six membrane

specimens were subjected to the primary ignition stage of the rocket engine with temperatures varying from 400 to 900 F and blast exposure times from 10 to 120 sec. Blast impingement angle was 90 deg. Thermocouples were used to determine temperatures in the exposure area.

24. The 24-in.-wide, 28-in.-long membrane test specimens were placed on a sheet of asbestos material which was then fastened securely to a section of aluminum panel. The edges of the membrane were held in place by steel strips. Photograph 18 shows the setup for the tests on uncoated membrane specimens.

25. The results of the tests of the nylon membrane without coating are as follows:

Test Specimen	Temperature °F	Exposure Time sec	Remarks
1	400	120	No visual effects
2	450	120	No visual effects
3	600	45	No visual effects
4	800	10	No visual effects
5	800	45	Burned
6	900	10	Burned

Photograph 19 shows the condition of test specimen 5 after exposure to 800 F for 45 sec, and photograph 20 shows test specimen 6 after exposure to 900 F for 10 sec. In each case, the nylon base fabric in the burned area became brittle and did not have any strength, and the neoprene coating around the burned area was brittle and could easily be "flaked off."

Coated membrane

26. One specimen of membrane coated with Dyna-Therm was subjected to the motor exhaust blast for 68 sec at a 45-deg blast impingement angle. The engine exhaust nozzle was 90 in. from the membrane. The specimen was placed on a sheet of asbestos which was then securely fastened to a section of aluminum panel. The test specimen was held to the panel and asbestos sheet by mild steel strips bolted around the edges. The specimen was placed beneath the rocket engine so the blast path would be parallel to the long axis. Five platinum-type thermocouples were inserted through the test specimen at 4-3/8-in. spacing so that their sensitive portions were in the Dyna-Therm coating. The test area before firing and the location of the thermocouples are shown in photograph 21.

27. The blast heat caused the aluminum panel supporting the test specimen to bow upward during the firing and some of the molten steel (melting point 2750 F) from the mounting strips to be blown from the test

area (photograph 22). Maximum temperatures recorded during the firing were as follows:

Thermocouple No.	Maximum Temperature, °F
1 (farthest from engine)	2150
2	2800
3	2500
4	2000
5 (nearest engine)	2200

Close examination of the specimen after the test (photograph 23) indicated that the Dyna-Therm coated material withstood the blast forces and the high temperatures of the model engine without burn-through. The failed areas along the perimeter of the specimen are attributed to edge effects, as the specimen was not of sufficient size to completely cover the impingement area of the rocket engine exhaust. Some of the Dyna-Therm coating was ablated, as the coating thickness decreased about 50 percent during the test. The membrane material showed no indication of excessive heat transfer through the coating, as the nylon base fabric did not appear to be damaged.

Summary of Results

28. A summary of results obtained in this investigation is as follows:

- a. Ceramic-coated aluminum panels withstood the blast of a liquid fuel engine for approximately 10 sec with a maximum temperature of 2500 F on the panel surfaces before appreciable damage occurred.
- b. The steel panels withstood the motor exhaust blast with a maximum temperature as high as 3300 F for a total exposure time of about 30 sec.
- c. The plastic panels sustained considerable damage during exposure for 20 sec to the full-stage blast of the model engine with an estimated maximum temperature of about 2800 F.
- d. The membrane without the protective coating burned through between 10 and 45 sec after exposure to the primary ignition stage of the model engine at a maximum temperature of about 800 to 900 F.
- e. The membrane with Dyna-Therm protective coating withstood the exhaust blast of the model engine for about 68 sec with maximum temperatures of 2500 to 2800 F. However, considerable ablation of the Dyna-Therm occurred during the test.

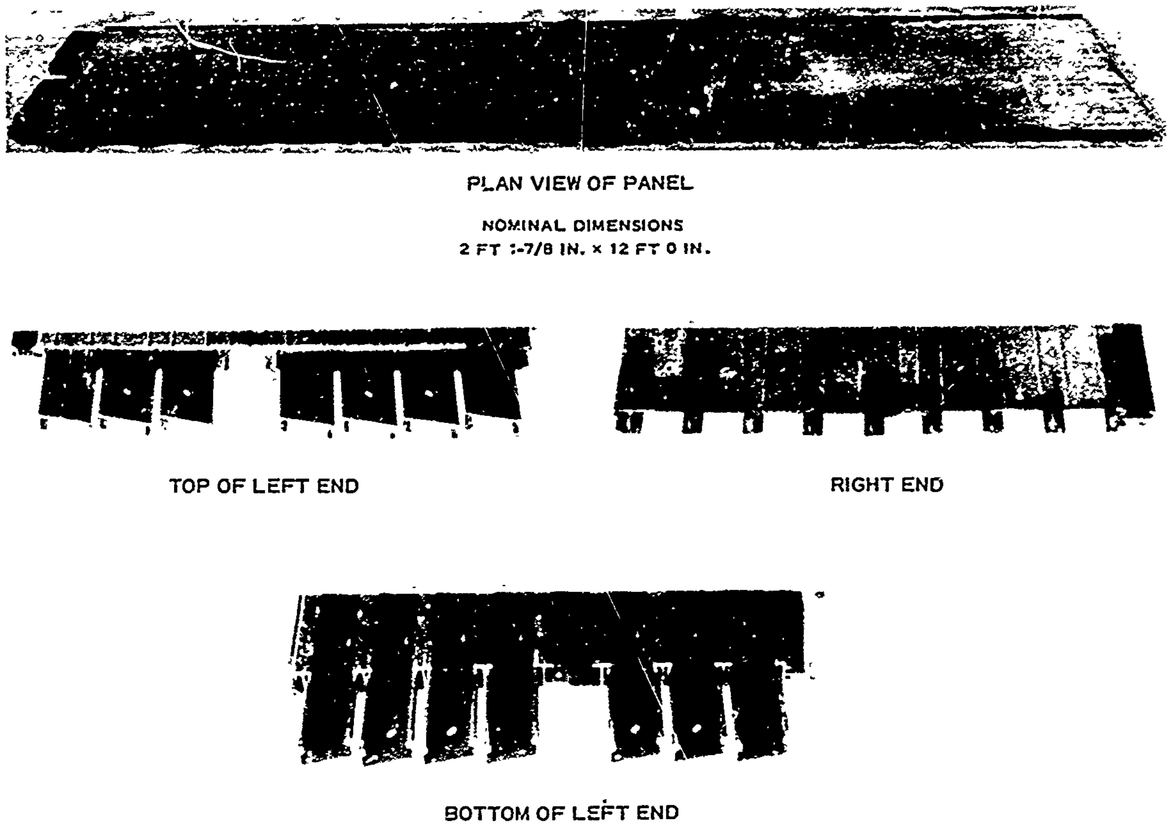
PART IV: CONCLUSIONS

29. As a result of this investigation, the following conclusions are believed warranted:

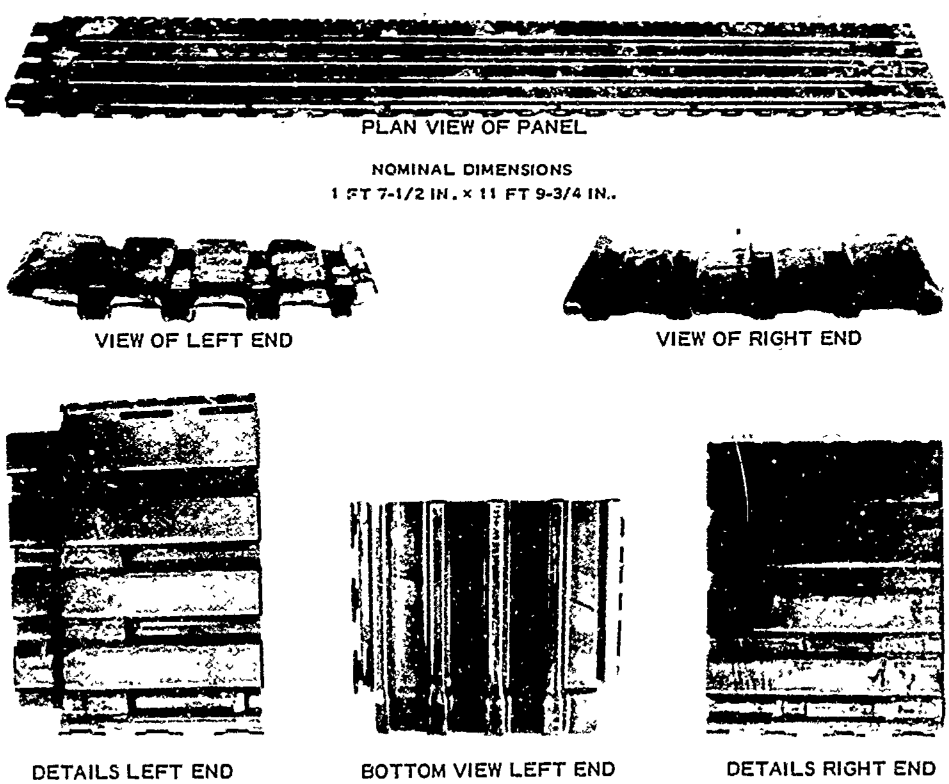
a. The ceramic coating increased considerably the capability of the aluminum panels to sustain rocket engine exhaust blast. The 6060-T6 aluminum alloy melts at about 1100 to 1200 F, and use of the coating enables the panels to withstand much higher temperatures (maximum of 2500 F) for at least 10 sec.

b. The steel panels without a protective coating will withstand exposure to higher blast temperatures than will the ceramic-coated aluminum panels.

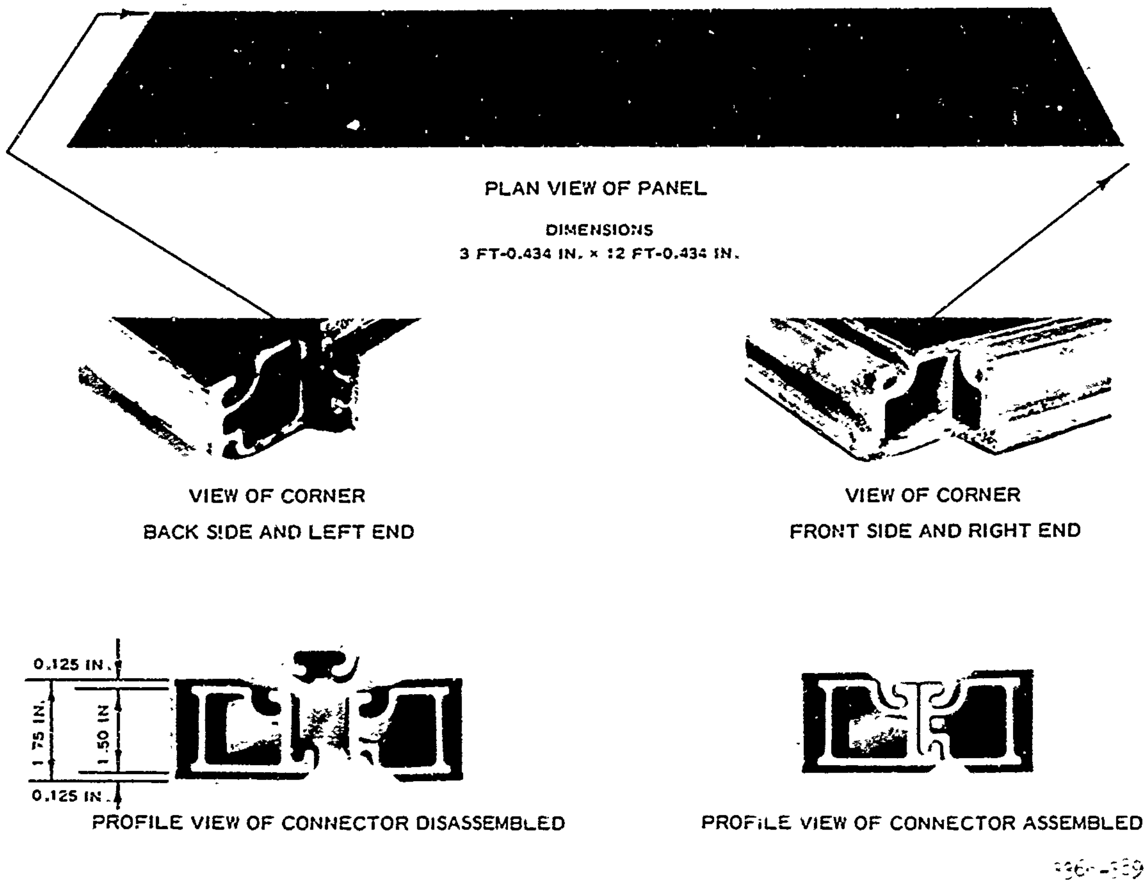
c. The Dyna-Therm coating on the T12 nylon membrane greatly increases the exposure time and maximum temperatures to which the membrane can be subjected without appreciable visible damage.



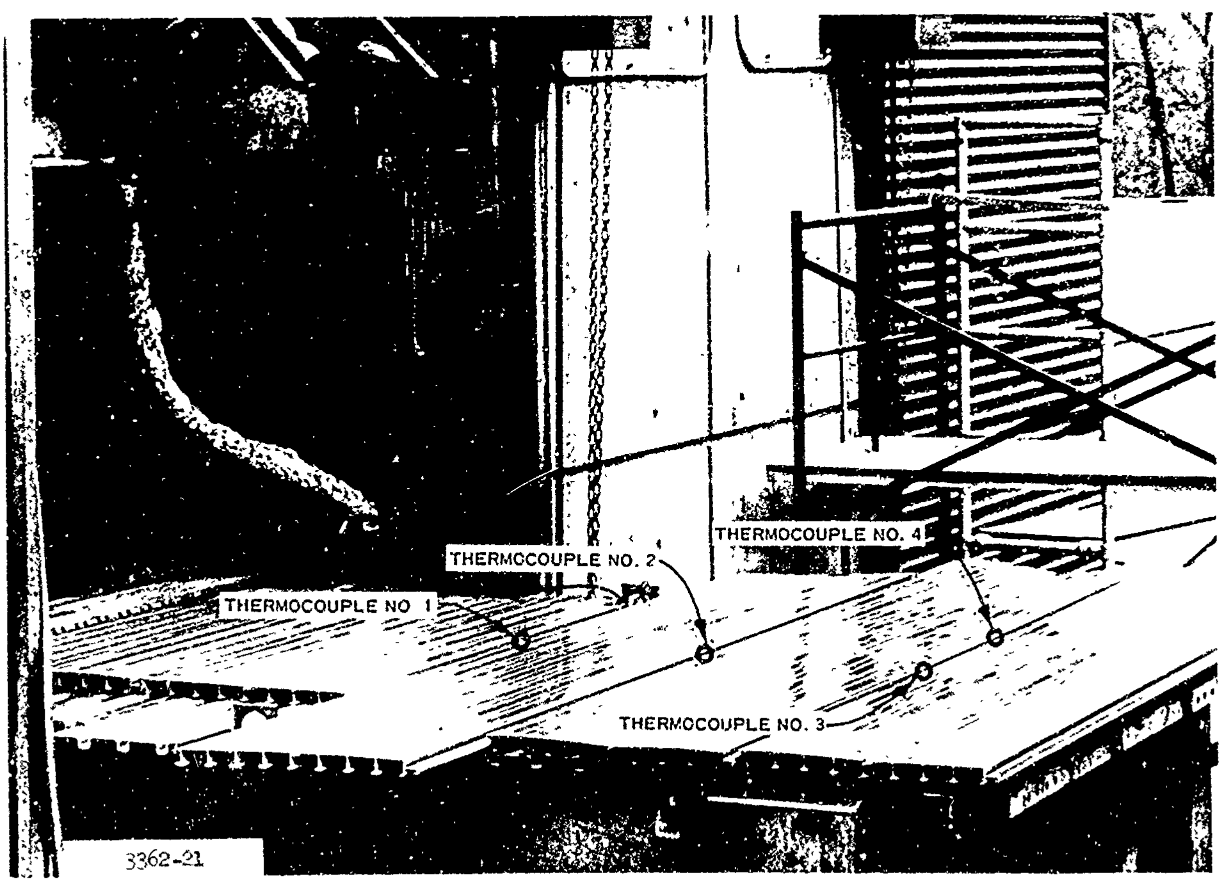
Photograph 1. T11 aluminum landing mat



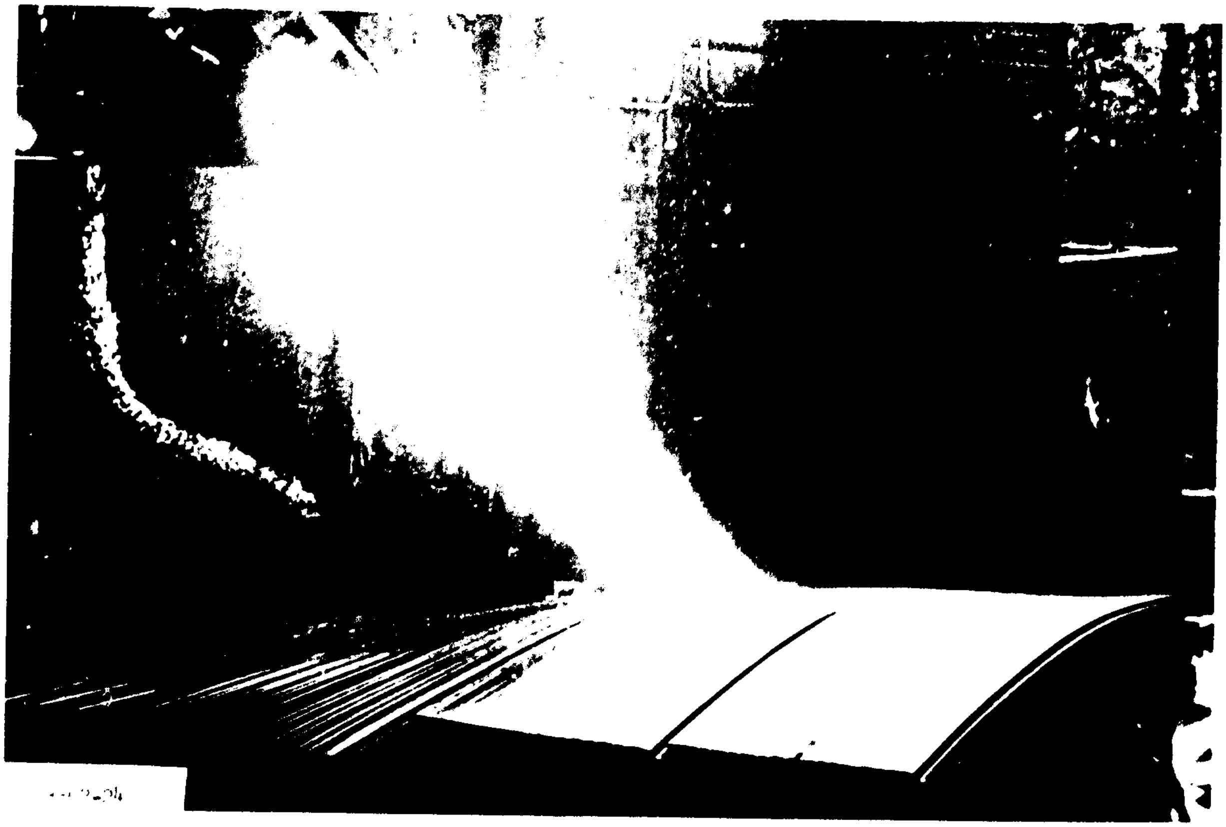
Photograph 2. Airplane landing mat, steel, dust-alleviation type, T-10



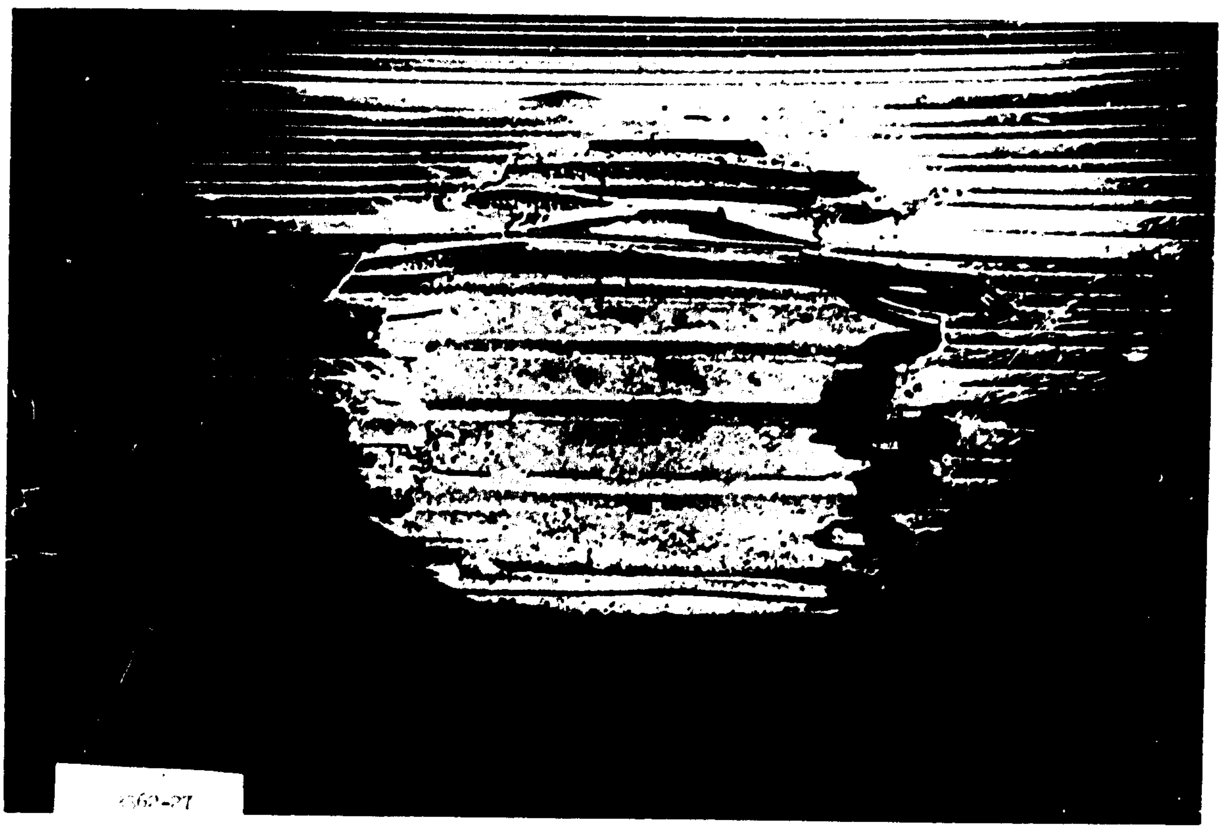
Photograph 3. T13 plastic landing mat



Photograph 4. Ceramic-coated panel test area

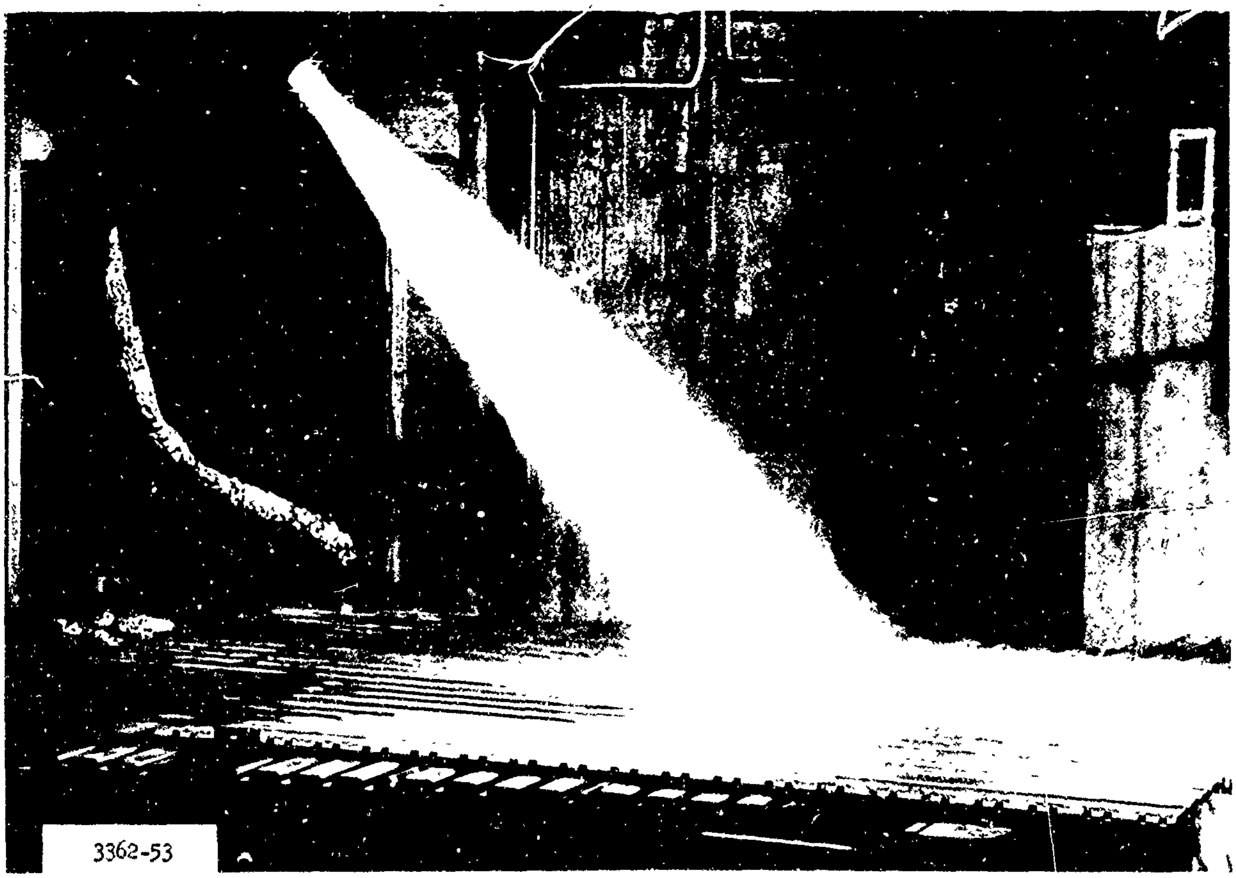


Photograph 5. Ceramic-coated panel blast test in progress

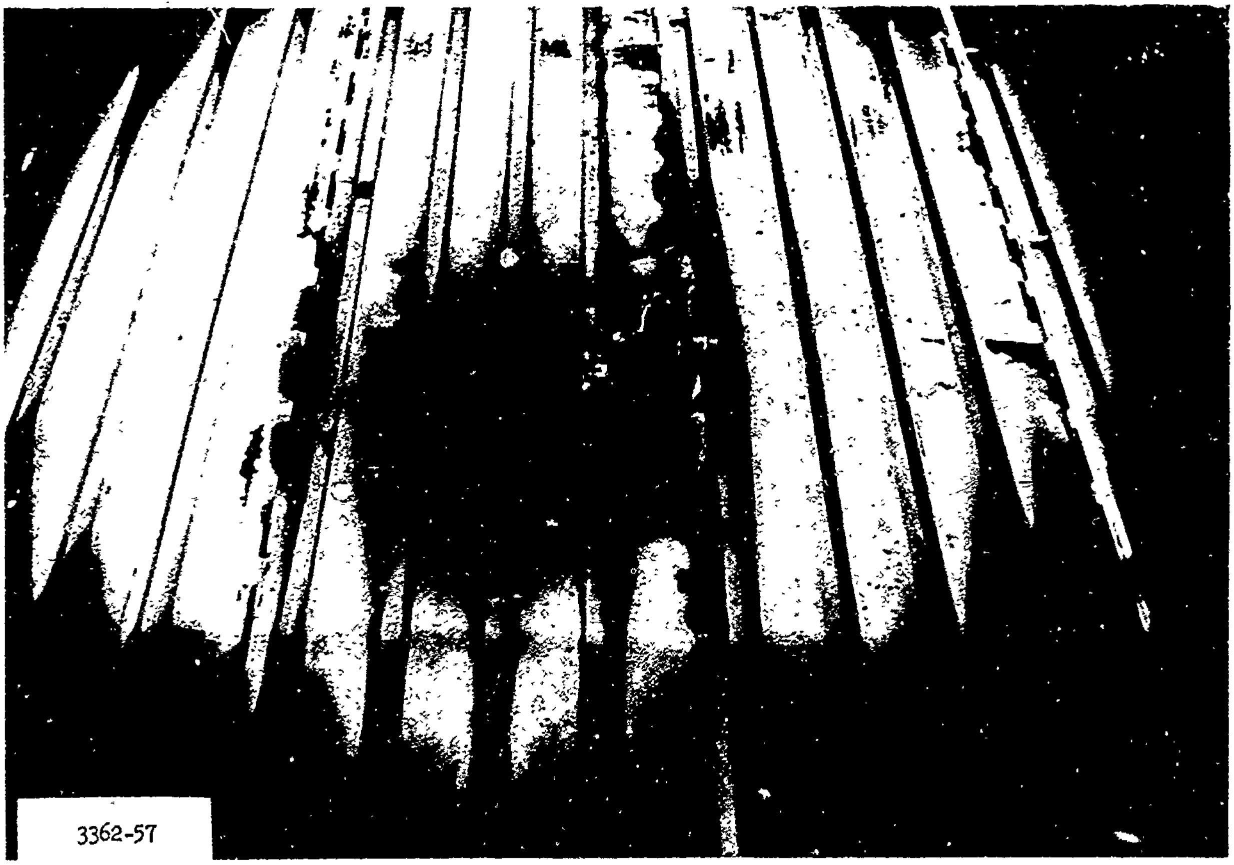


Photograph 6. Ceramic-coated panel surface after test

Photograph 7. Steel panel test area, first test

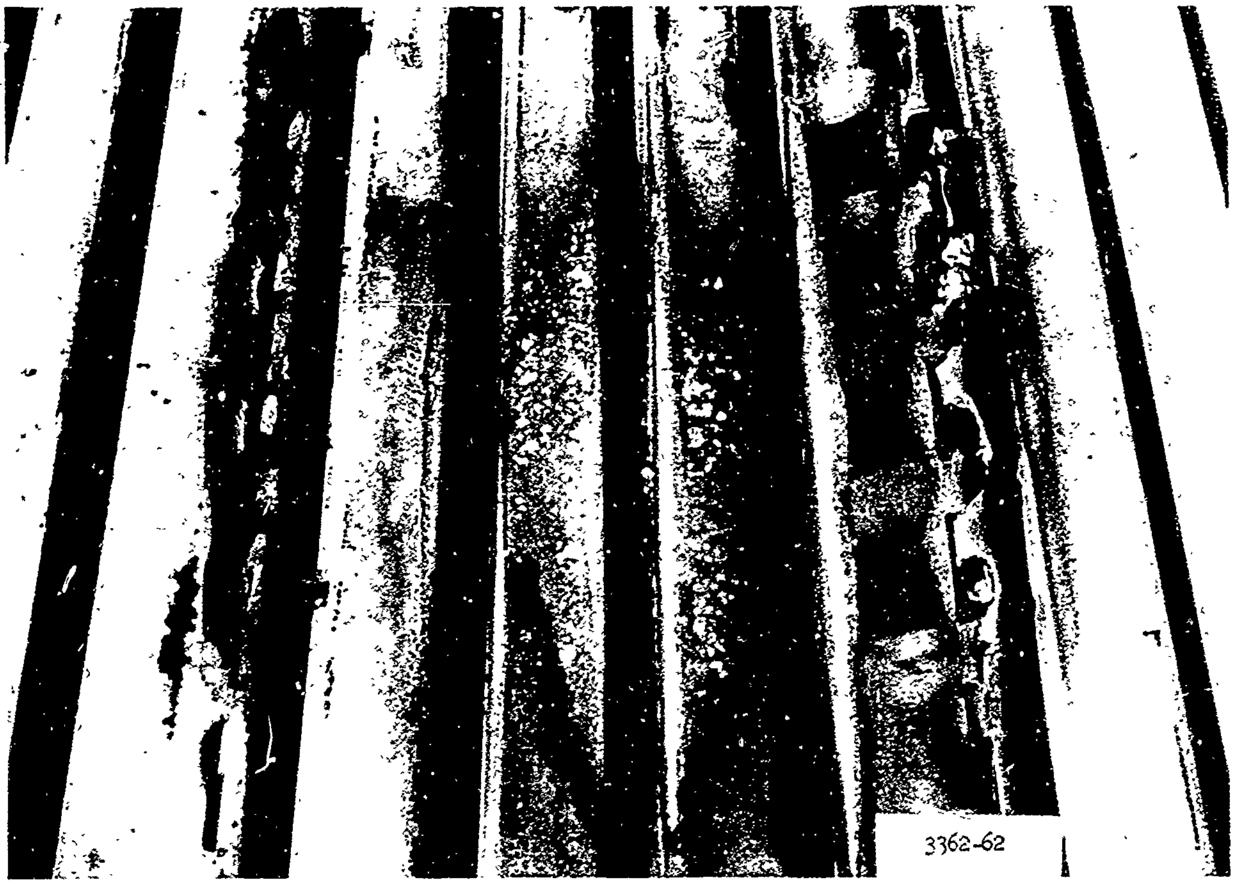


Photograph 8. Steel panel blast test in progress

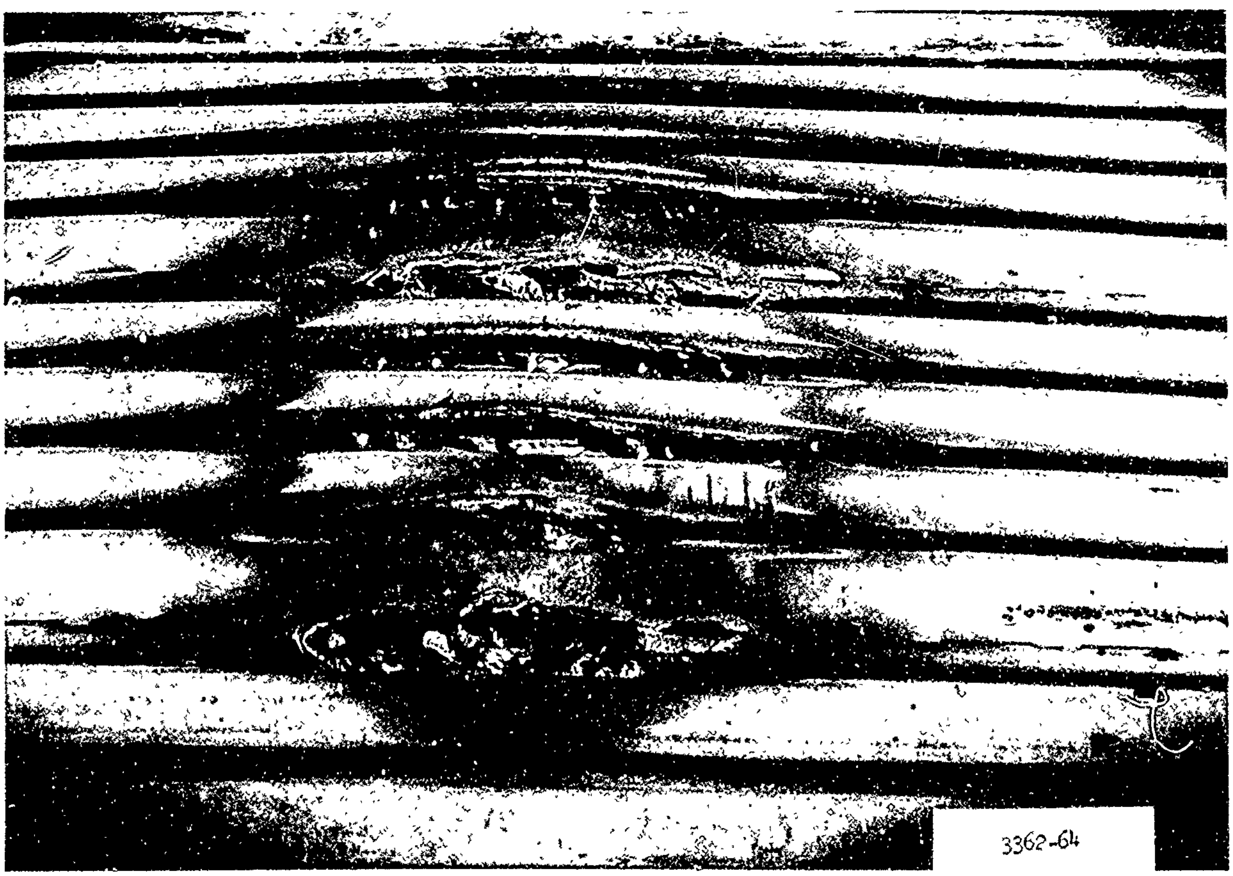


Photograph 9. Steel panel surface after first test

Photograph 10. Close-up of steel panel damaged area after first test

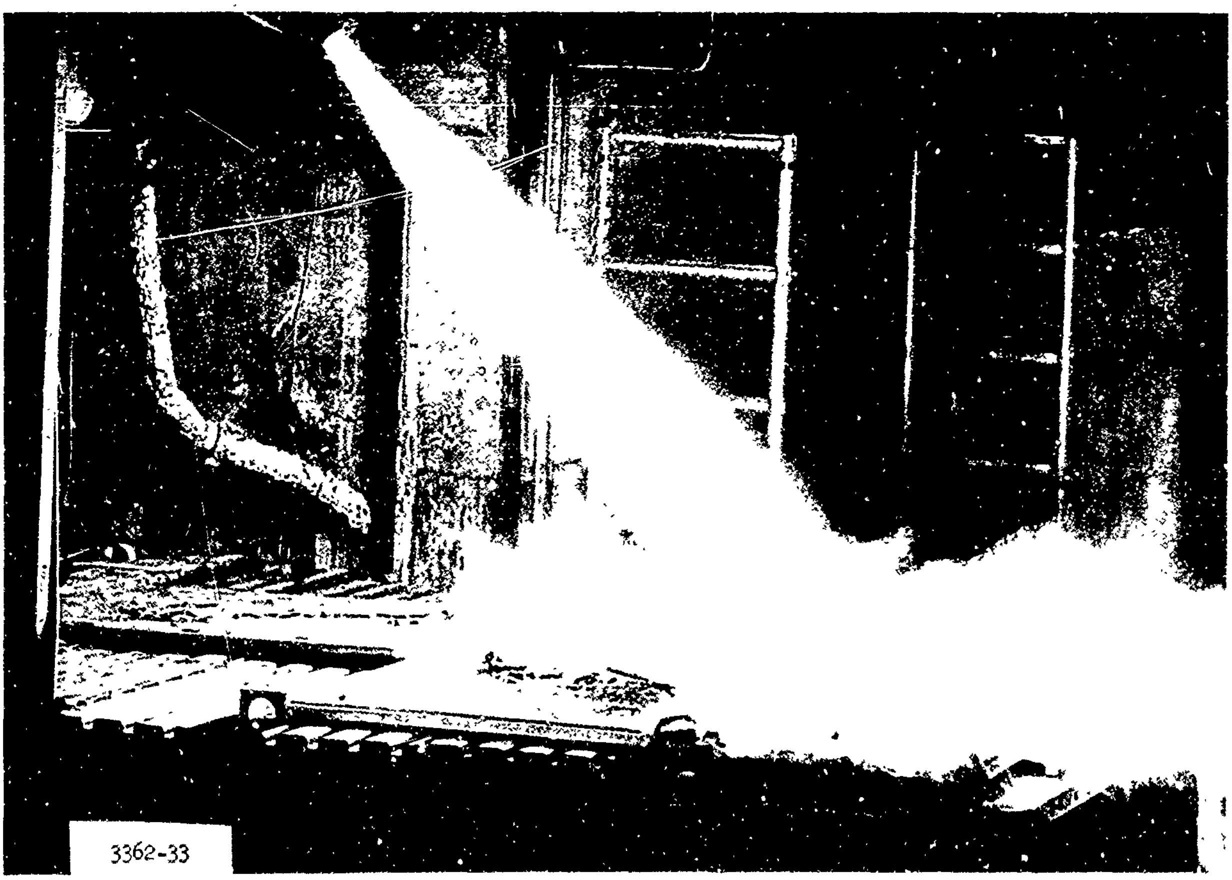


Photograph 11. Steel panel surface after second test

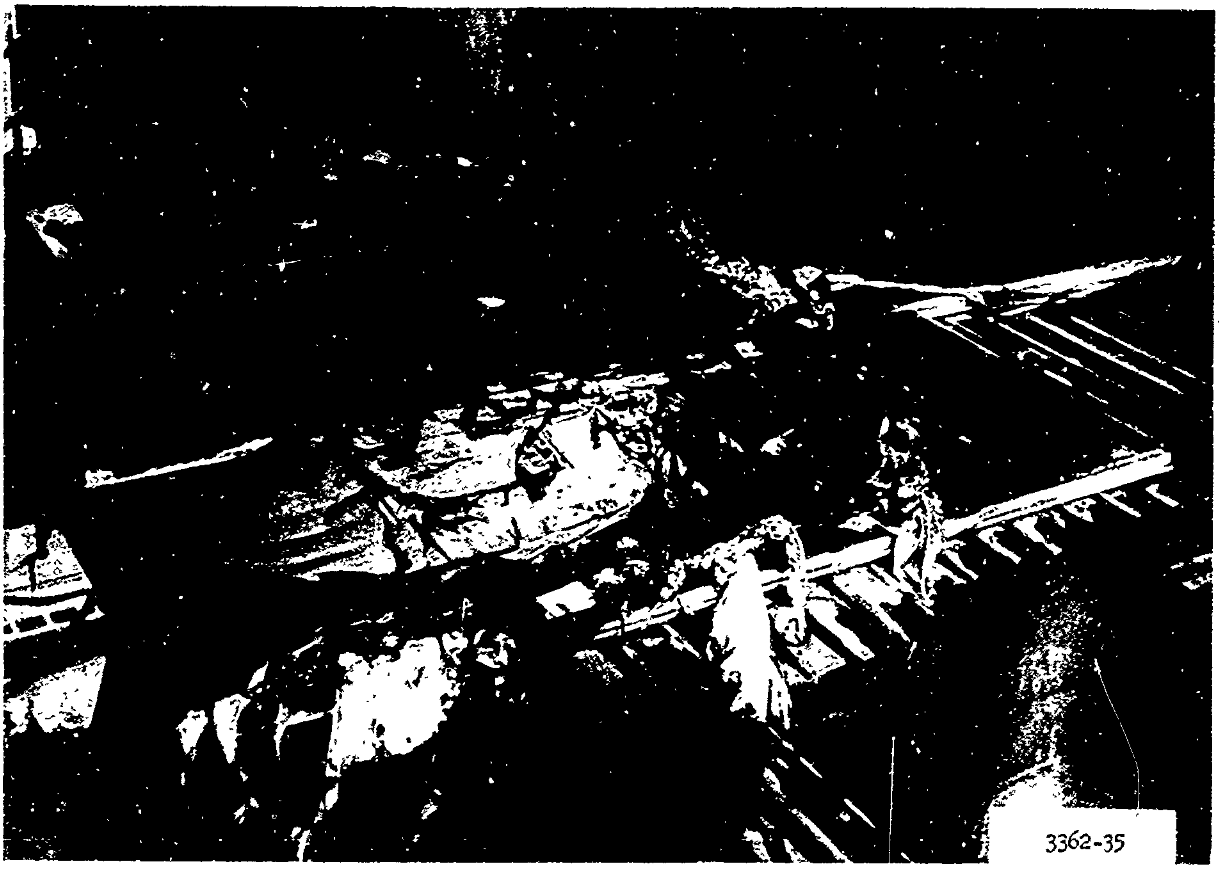


Photograph 12. Steel panel surface after third test

Photograph 13. Plastic panel surface before test

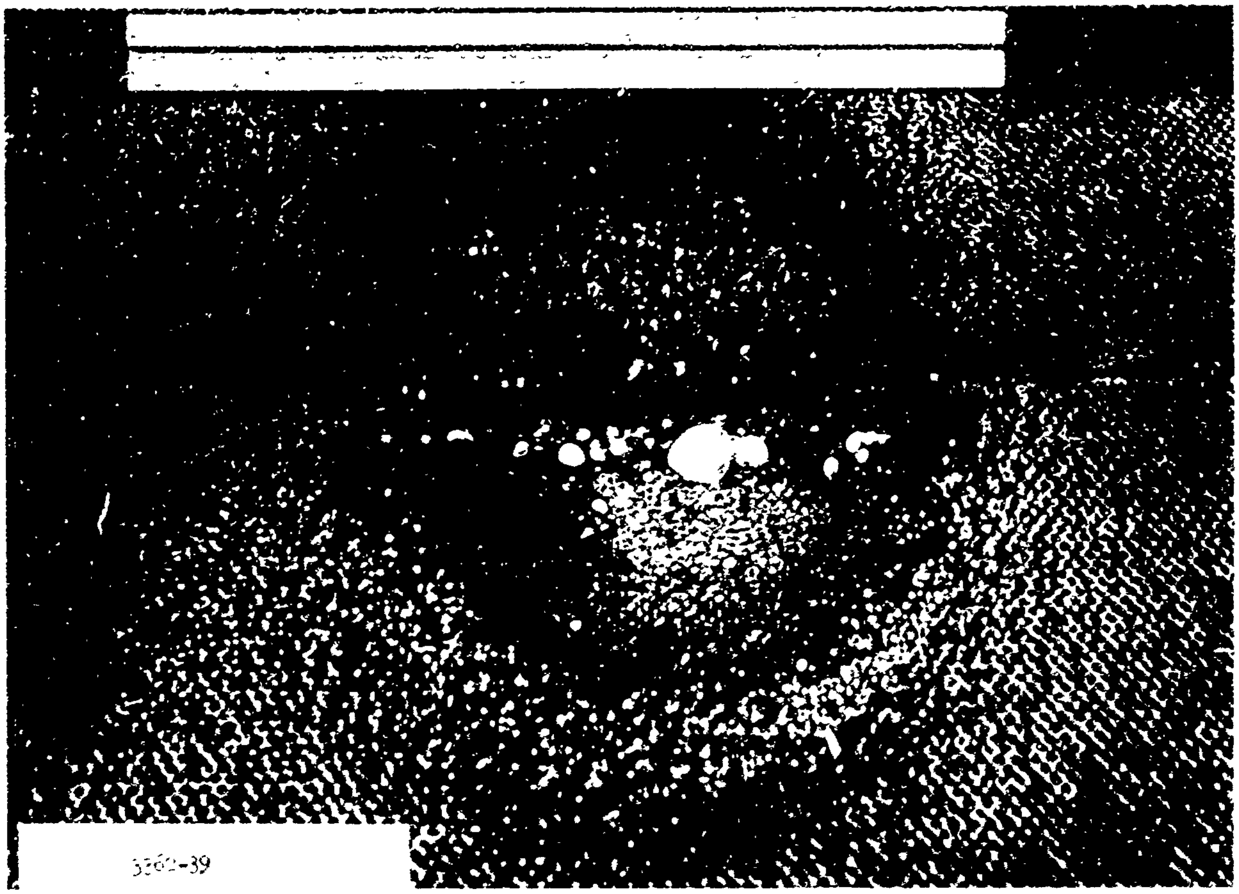


Photograph 14. Plastic panel blast test in progress

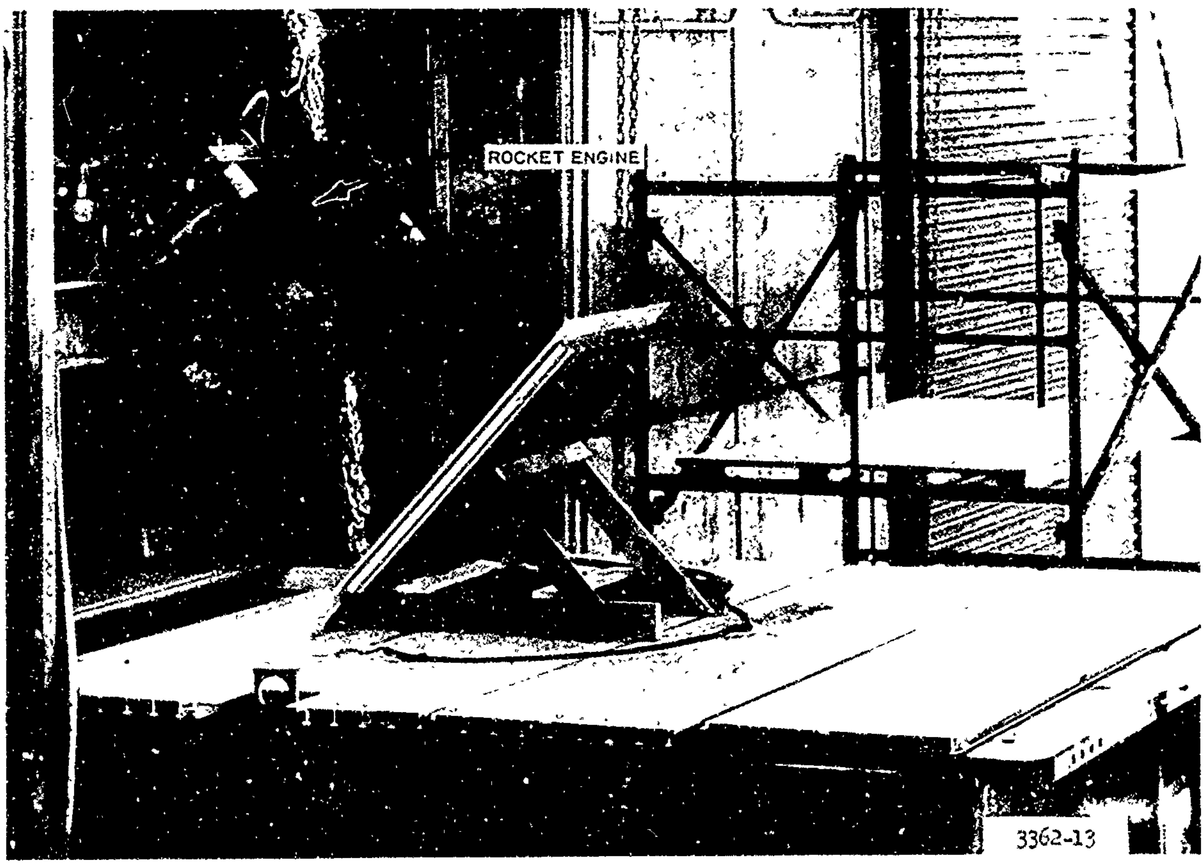


Photograph 15. Plastic panel surface after test

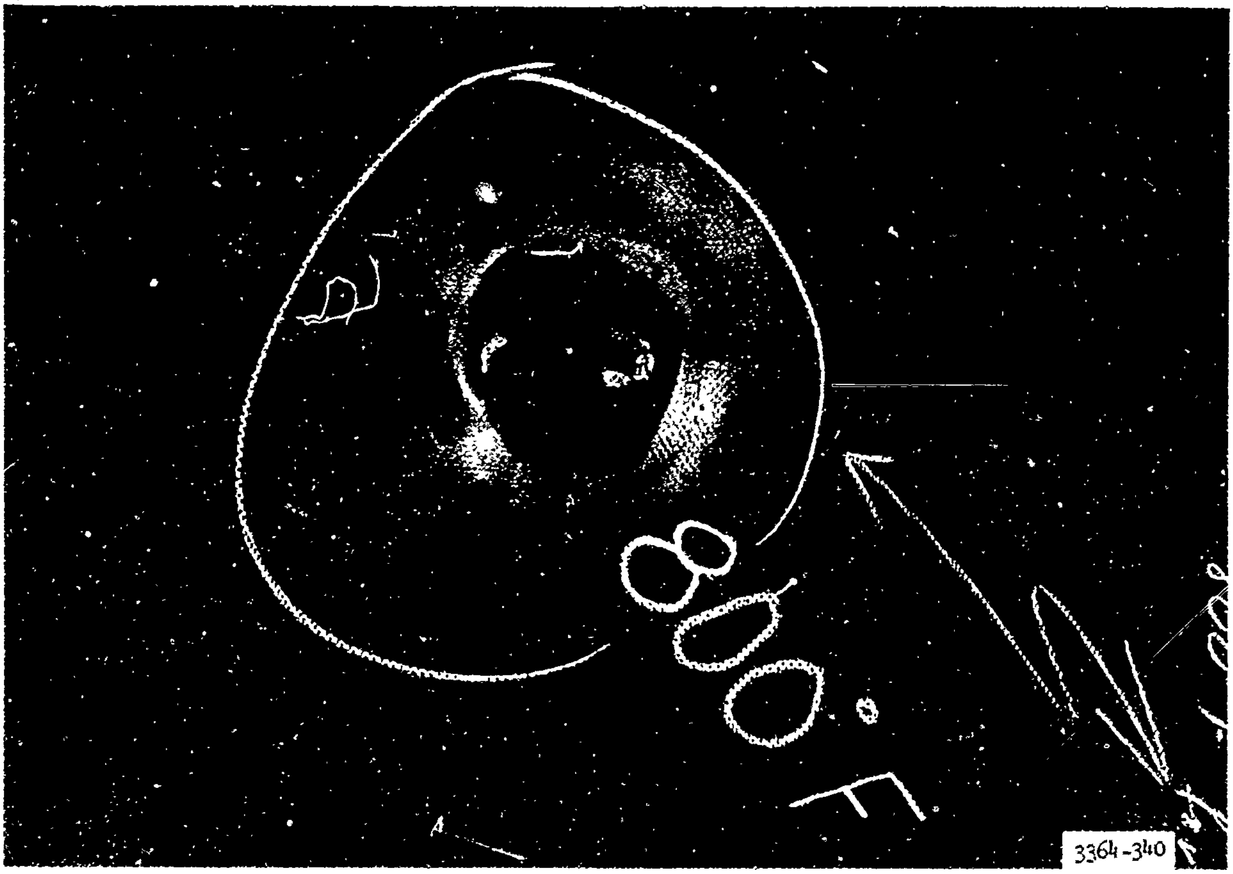
Photograph 16. Plastic panel surface after test (main impingement area)



Photograph 17. Close-up of main impingement area on plastic panel.
Note globules of molten glass

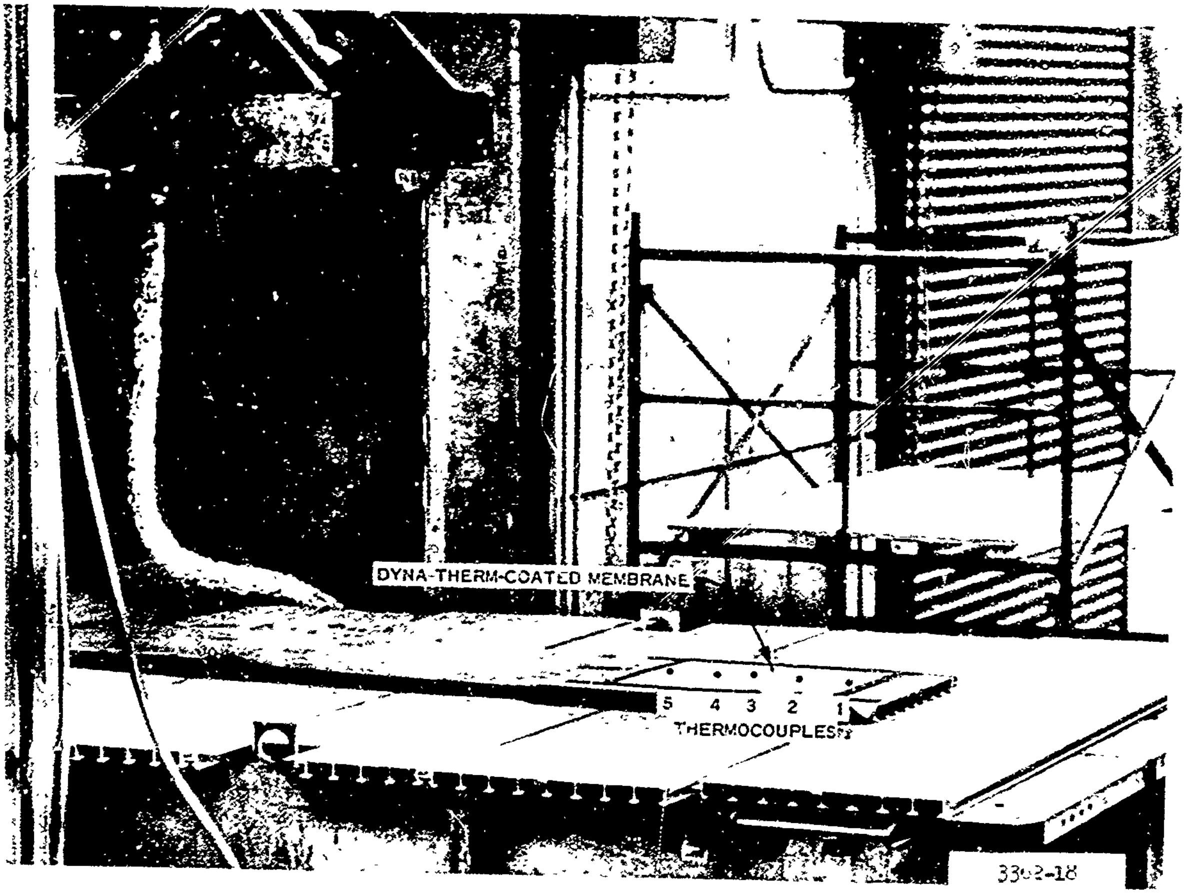


Photograph 18. Uncoated membrane test setup



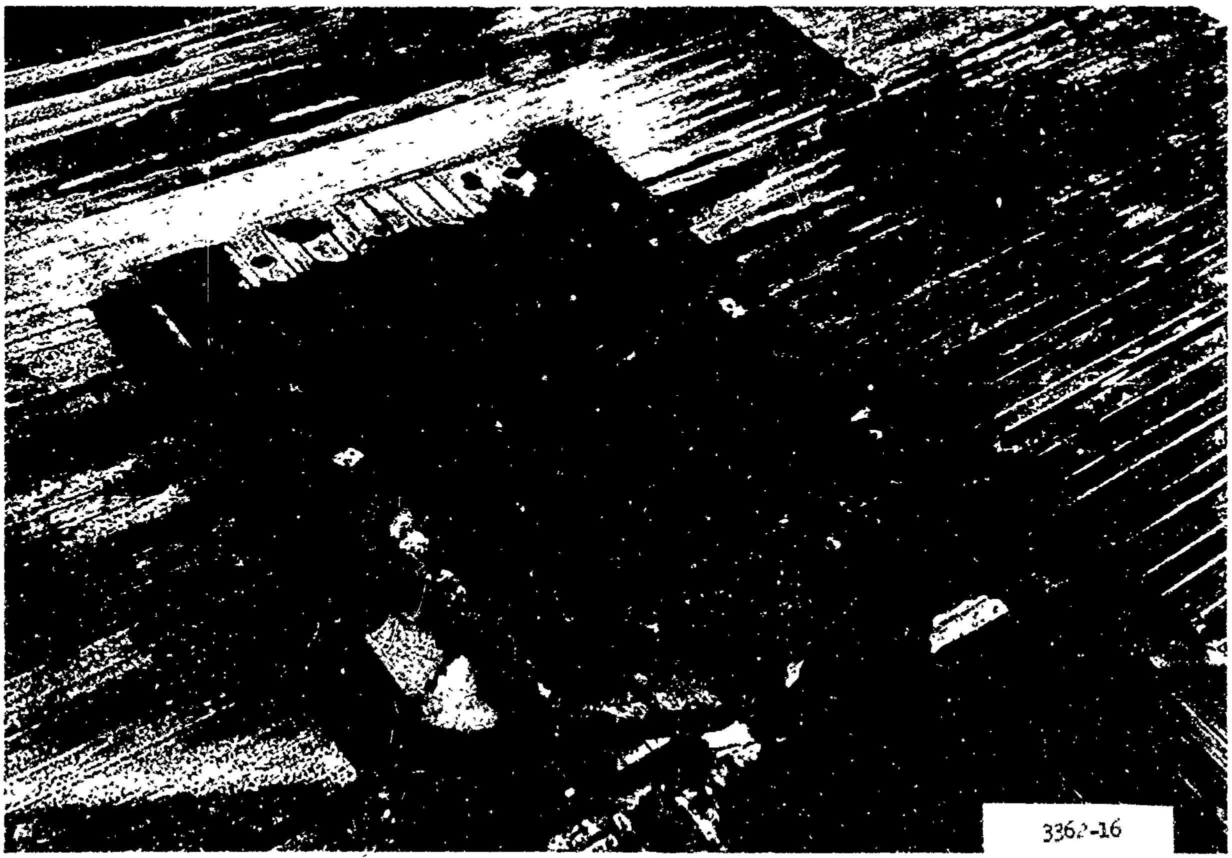
Photograph 19. Membrane specimen 5 after test

Photograph 20. Membrane specimen 6 after test

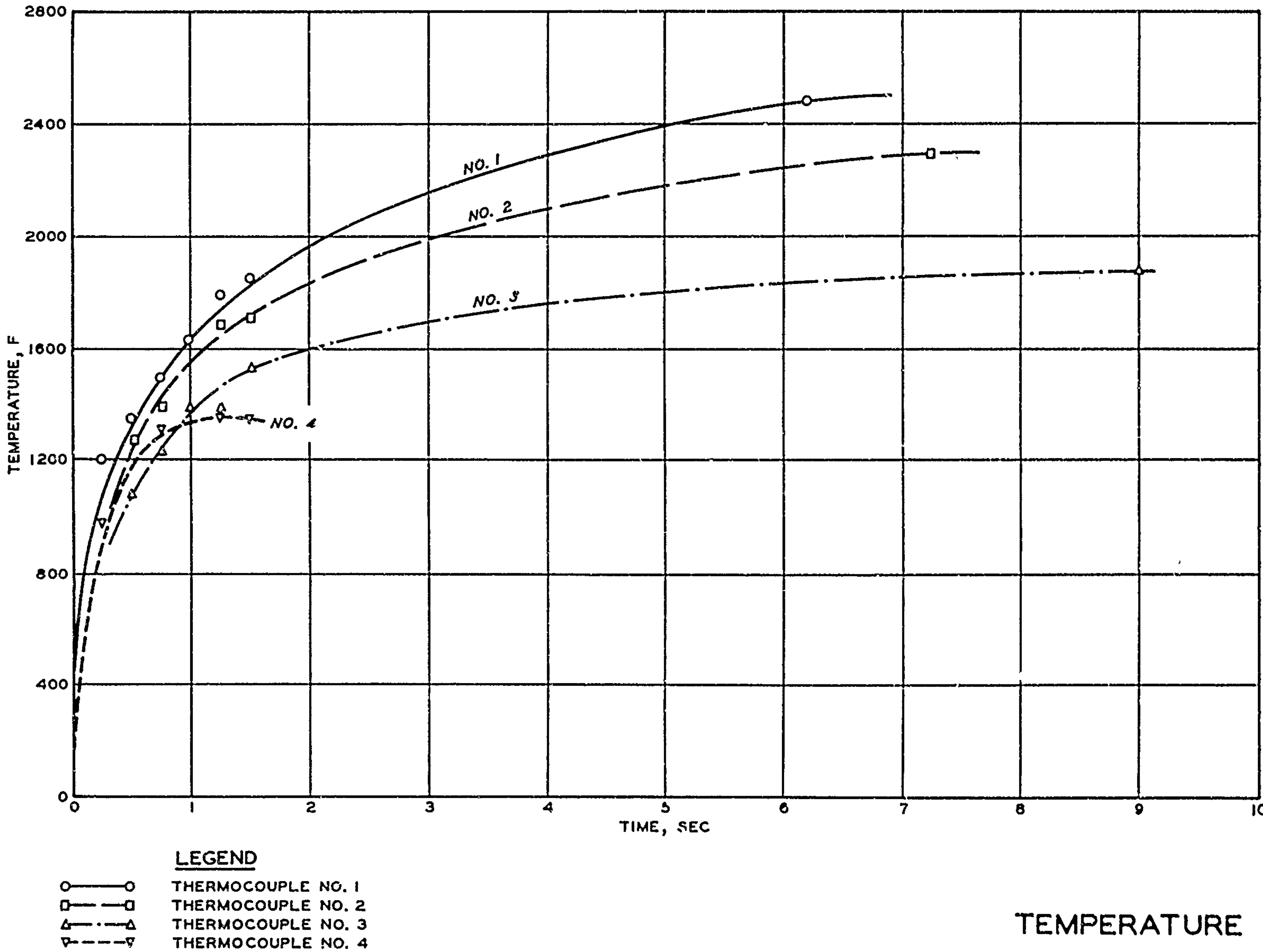


Photograph 21. Dyna-Therm test area

Photograph 22. Dyna-Therm coating blast test in progress



Photograph 23. Dyna-Therm coating after test



TEMPERATURE VS TIME
CERAMIC-COATED PANEL TEST

PLATE I

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Report 1 of series

5. AUTHOR(S) (Last name, first name, initial)
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10. AVAILABILITY/LIMITATION NOTICES
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U. S. Army Materiel Command Washington, D. C.

13. ABSTRACT
Blasts tests with a 500-lb-thrust rocket engine were conducted on (a) ceramic-coated aluminum blast panels, (b) steel panels, (c) plastic panels, and (d) nylon membrane with and without a heat-resistant coating to determine the capabilities of these items to withstand the high temperatures and velocities generated during the firings. Based on results obtained in this investigation, the following conclusions are believed warranted: (a) The steel panels without protective coating will withstand exposure to higher blast temperatures than will the ceramic-coated aluminum panels. (b) The ceramic coating on the aluminum panels and the heat-resistant coating on the nylon membrane greatly increase the capabilities of these items to resist the rocket engine exhaust blasts. (c) The plastic panels sustained considerable damage during exposure for 20 sec to the full-stage blast of the model engine.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Rockets						
Blast						
Ground surfacing						
Ceramic coatings						
Aluminum						
Steel						
Plastics						
Nylon						

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